

Nonlinear Wave Group Evolution to Breaking- Innovative Measurements and Analysis

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LONG-TERM GOALS

As marine winds strengthen, breaking waves dominate the dissipation of wave energy of the wind seas. These breaking events also produce upper ocean turbulence, foam and subsurface bubbles, spray, enhanced microwave backscatter and underwater ambient noise, and locally increase the aerodynamic wind drag on the sea surface by up to a factor of two.

Despite the widespread occurrence of wave breaking, present knowledge on what determines initiation and strength of breaking events has been fragmentary. A recent advance (Song and Banner, 2002, Banner and Peirson, 2007) associates deep water wave breaking with convergence of wave energy within wave groups driven by nonlinear interactions. This leads to individual wave steepening, and possible breaking. Evidence is building that there is a ‘generic’ threshold wave energy convergence rate for breaking onset in deep water (e.g. Banner et al., 2002).

Observational field studies have reported interesting statistics on breaking crest length as a function of scale (Phillips et al, 2001, Melville and Matusov, 2002). The more recent study of Gemmrich (2005) also spans a range of wave age conditions. Laboratory studies of wave breaking losses for both 1D and 2D cases (eg. Rapp and Melville, 1990, Nepf et al, 1998, Wu et al, 2002) have also provided valuable insight on energy losses as a function of upstream conditions and transverse non-uniformity. However, a compelling perspective on the mechanisms that determine breaking initiation and strength has not emerged from these studies. Very impressive computational simulations using LES and smooth particle hydrodynamical techniques have also been published. However, their capacity to reproduce breaking initiation and losses/loss rates of the dominant seas within a spatially extensive domain has yet to be demonstrated.

Overall, a deterministic framework for predicting breaking onset and energy loss/loss rate in a phase-resolved, directional wind sea is presently lacking. This incomplete knowledge of wave breaking presents a fundamental difficulty for the delivery of accurate phase-resolved wave forecasts. Such forecasts would be valuable for Navy operations especially in higher sea states.

Within this context, the long-term objective of this effort is to contribute the knowledge and parameterization of wave breaking physics to two key issues in this DRI: “Can wave breaking characteristics be measured and quantified?” and “How well can wave-resolving models predict short term wave field evolution (i.e. over 10-100 main wave periods)?”. These are central issues in providing actual wave forecasts, in contrast to the present statistical forecast of significant wave height.

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OBJECTIVES

Specifically, this proposal is focused on understanding and predicting the onset and strength of dominant breaking events in terms of the evolution of nonlinear wave groups or packets, with no restriction on the group geometry. These could range from near-unidirectional groups that persist for significant durations, to rapidly evolving ‘chirped’ structures from intersecting directional wave packets. In this context, the major research focus is on the characterization and prediction of group-mediated wave breaking onset and energy losses/loss rates for the dominant sea waves, especially during strong wind forcing conditions greater than 20 knots.

The proposed effort involves innovative analysis of the gathered shipboard radar and co-located phase-resolved wave model data. Once a suitable data set becomes available from the observational phase of this DRI, the aim is to validate a new perspective for predicting the onset and energy loss/loss rates from breaking of the dominant wind waves. This builds on the following well-known properties of ocean waves: (a) groupiness in ocean wave records (b) energy focusing within nonlinear wave groups and (c) a strong correlation of breaking onset at envelope maxima of wave groups. Holthuijsen and Herbers (1986) provide very convincing observational evidence for this perspective.

A quantitative basis for this new perspective on breaking derives from the approach introduced in Song and Banner (2002) and Banner and Peirson (2007). These papers describe how a growth rate parameter based on the rate of wave energy focusing and geometrical steepening at the envelope maximum controls both the breaking onset and energy loss/loss rate, thereby providing a more robust determinant for both of these properties than any in present use, such as the local wave steepness.

The proposed investigation seeks to extend this approach to field conditions, through an innovative analysis and modeling interface program with the following primary objectives:

- (i) *assess the validity of this new perspective on wave breaking from the data gathered for the more complex conditions that occur for wind driven ocean waves, compared with the laboratory.*
- (ii) *from the outcome of (i), provide a basis for improving modeling of breaking initiation and breaking energy loss/loss rate in the phase-resolved wave computational effort within this DRI.*

APPROACH

Our effort in FY08-10 proposes to focus on performing novel data analyses, particularly on the wave breaking aspects that are needed to optimize present computational modeling capabilities. Further knowledge on this aspect of the process is needed for accurately forecasting the local phase-resolved wind wave field.

The motivation for this new perspective on breaking was the modeling study of Song and Banner (2002). Their findings on breaking initiation were confirmed in the recent laboratory study of unidirectional wave groups by Banner and Peirson (2007). They established observationally that a non-dimensional growth rate parameter $\delta(t)$, based on the rate of wave energy focusing and geometrical steepening at the envelope maximum appeared to control both the breaking onset and the strength of breaking. The figure below from Banner and Peirson (2007) shows the clear improvement in relating the relative breaking energy loss to the parametric energy convergence rate δ_{br} at breaking onset,

compared with the geometrical parameter S , the maximum steepness measure previously proposed as the best slope parameter to correlate available breaking loss data (Rapp and Melville, 1990). Note the major improvement for a wave steepness S near 0.15. A very similar improvement was found for the dissipation rate correlation.

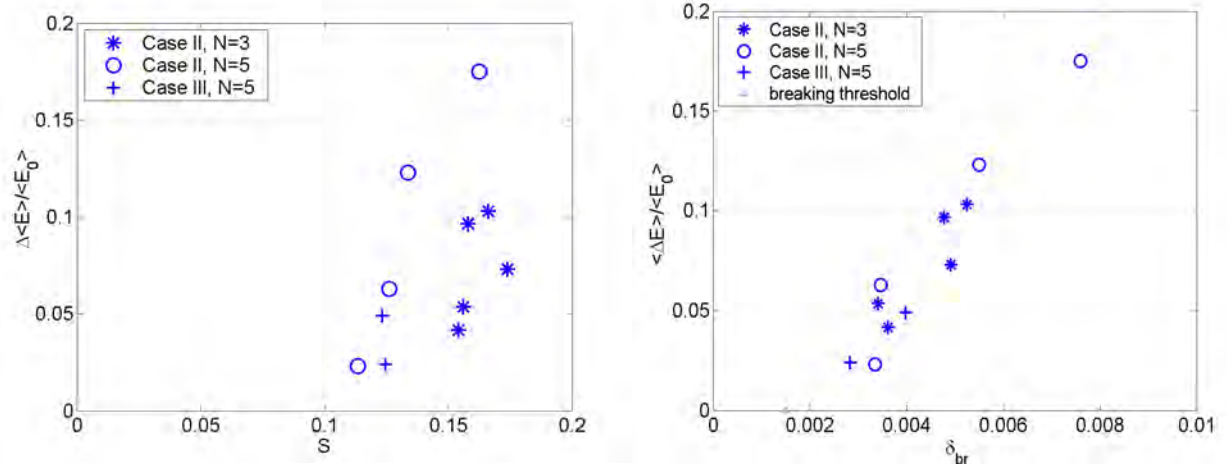


Figure 1. Experimental correlations for breaking energy loss for 2D nonlinear wave groups: left panel shows loss as a function of the maximum steepness parameter S just prior to breaking; right panel shows loss as a function of the energy convergence rate parameter δ_{br} just prior to breaking.

The approach to be adopted in this study is to use data gathered during the Hi-Res ASI open ocean observational experiment to investigate the validity of the energy focusing perspective on wave breaking. The required data is W. Plant's shipboard Doppler radar, and/or the WAMOS radar, and A. Jessup's Helikite breaking wave imagery.

The data from the radars will provide backscattered power and Doppler velocities that define the observed wave group evolution. Co-located, synchronous wave breaking data will be available from the Doppler radar velocity data and independently from the synchronous Helikite whitecap imagery.

To address objective (i): identify and measure the evolution of a wave 'group' on a timescale short compared with a carrier wave period; calculate the group envelope and its maximum, and then follow the evolution of the group maximum. From this data and the local carrier wavenumber computed from the carrier wave data, calculate the dimensionless growth rate δ and its value just prior to breaking δ_{br} .

The initial focus will be on cases where the dominant wind seas are long-crested as this is closest to the recent numerical modeling and wave tank investigations. However, breaking can occur through obliquely intersecting waves, and the same generic energy convergence mechanism may be operative. This needs to be investigated. Our initial effort to determine breaking onset and loss would be based on determining the parametric energy convergence rate. Other signal analysis techniques, presently being developed collaboratively with Chapron (IFREMER, France) would also be investigated.

To address objective (ii): The goal is to provide a physical basis for improving the modeling of breaking initiation and breaking energy loss/loss rate in the complementary phase-resolved wave computational effort of other PIs. Our study of unidirectional nonlinear wave group behavior indicates

a common threshold for the parametric growth rate $\delta(t)$ that identifies groups that will evolve to break. Further, $\delta(t)$ at breaking onset appears to determine the ensuing breaking energy loss/loss rate (Banner and Peirson, 2007). This will be investigated for ocean wave groups in detail in this DRI.

If it is found to be applicable in its present form, or in a modified form appropriate to more complex sea conditions, this perspective would be built into the modeling to refine the occurrence of breaking onset and subsequent energy loss/loss rate (or recurrence) where the dominant waves locally steepen. This would involve a close interaction with the wave modeling groups in this DRI to implement and test this approach in their computations.

WORK COMPLETED

In FY07, the focus of this PI was on contributing strategically to the one-year planning phase of this DRI, emphasizing the perspective described above. There were two intensive planning meetings held at the Scripps Institution of Oceanography (SIO) in November 2006 and June 2007. From these meetings, a prioritized set of objectives and a final scientific plan were developed. Among the priorities was the capability to quantify the wind energy flux to the dominant waves. Accordingly, the scope of my original proposal was expanded to include an option to deliver accurate measurements of wind input to the dominant sea waves (for up to 3.5m waveheights). Very considerable effort went into extending my final HiRes proposal to ONR to perform these measurements. This involves deployment from FLIP of an ocean-going wave follower servo-mechanism with surface pressure sensing capability. A companion DURIP proposal was developed and submitted for the specialized boom support structure for mounting the wave follower from FLIP.

RESULTS

There are no results at this preliminary stage of the DRI.

IMPACT/APPLICATIONS

This effort will contribute to a far more detailed characterization of the evolution of the dominant wind sea waves wind driven air-sea interface. It will perform novel analyses on wave group structure aspects of these wind seas, and investigate the proposed connection with breaking onset. If the wind input option is pursued, the data gathered and analysed in this project will further complement the information needed to accurately forecast the evolution of the phase-resolved dominant wind sea.

RELATED PROJECTS

The present project is related generically to our effort on modeling wave breaking in the CBLAST Hurricane DRI entitled: 'Wave breaking influence in a coupled model of the atmosphere-ocean wave boundary layers under very high wind conditions'. While the wind speed regimes in Hi-Res DRI and CBLAST Hurricane DRI are different, common elements in these two projects include the need to better understand and parameterize the breaking process and how it occurs at the different wave scales. Our CBLAST effort has resulted in a capability for forecasting wave breaking of the dominant waves. These forecasts validate very well at moderate wind speeds of around 12 m/s, while validation for hurricane conditions awaits the data processing by other CBLAST PIs.

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